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EXPLOSIVELY WELDED STEEL PATCHES FOR THE FIELD REPAIR OF ROLLED HOMOGENEOUS ARMOR

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A feasibility study was conducted to determine whether explosively welded steel patches could be used for battlefield repair of tank armor. Mild steel patches were bonded to rolled homogeneous armor plates in the laboratory and to the glacis and turret of a tank in the field. The patch design used a circular weld pattern, slurry explosive, a thin edge for ease of welding, and a reinforced center for additional strength and protection. Surface preparation was found to affect weld quality.

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The authors are grateful to James Ogilvie of the U.S. Army Tank-Automotive Command (TACOM) for proposing that explosive welding be used to make battlefield repairs on armored vehicles, and to Dr. Gerald Moss of the Lanxide Corporation for suggesting that the patches be welded only along their edges.

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1. INTRODUCTION

Explosive welding has become an accepted metal-working procedure. It has been used primarily for dissimilar metals which are difficult to weld by other methods and for welding in inaccessible locations, e.g., plugging pipes in heat exchangers and construction in rugged terrain. Wider use of this technique will always be constrained by safety considerations associated with explosives, but there remain many applications where explosive welding could be exploited. The International Conferences on High Energy Rate Fabrication (HERF) include papers showing applications of explosive welding and provide data on welding parameters for many materials (Center for High-Energy Forming 1967, 1969, 1971, 1973, 1975, 1977; Blazynski 1981; Berman and Shroeder 1984).

This study examined the feasibility of using explosive welding to repair tank armor in the field. The Army has a variety of techniques which are now used for battlefield repairs, but they do not offer the level of protection which a welded steel patch would convey. Since this was envisioned as a temporary repair, it was not essential to make the patch from armor plate. In most cases the repair needs to cover a hole in the vehicle's armor plate. A weld pattern that does not directly load the center of the plate is advantageous since this approach reduces the probability of forcing the flyer plate into the hole and tearing the patch.

A schematic diagram of an explosive welding process is illustrated in Figure 1. Successful welding depends upon several criteria. The dynamic collision or bend angle between the plates, β, must fall in the range which produces jetting that cleans the material ahead of the weld point. The plate velocity, V_p, must be high enough for the impact to cause metal deformation and flow, but must not be so high that the kinetic energy (KE) causes excessive melting in the welding zone. The welding point velocity, V_w, must be less than 1.25 times the sound velocity of the materials used to prevent rarefaction waves from disrupting the weld. Data are available for welding many combinations of materials but parameters were not located for the specific combination to be welded, mild steel to rolled homogeneous armor (RHA) (Orava and Wittman 1975).

Beta, the dynamic bend angle, is a function of various welding parameters and is presented in equation 1 (Wylie, Williams, and Crossland 1971).

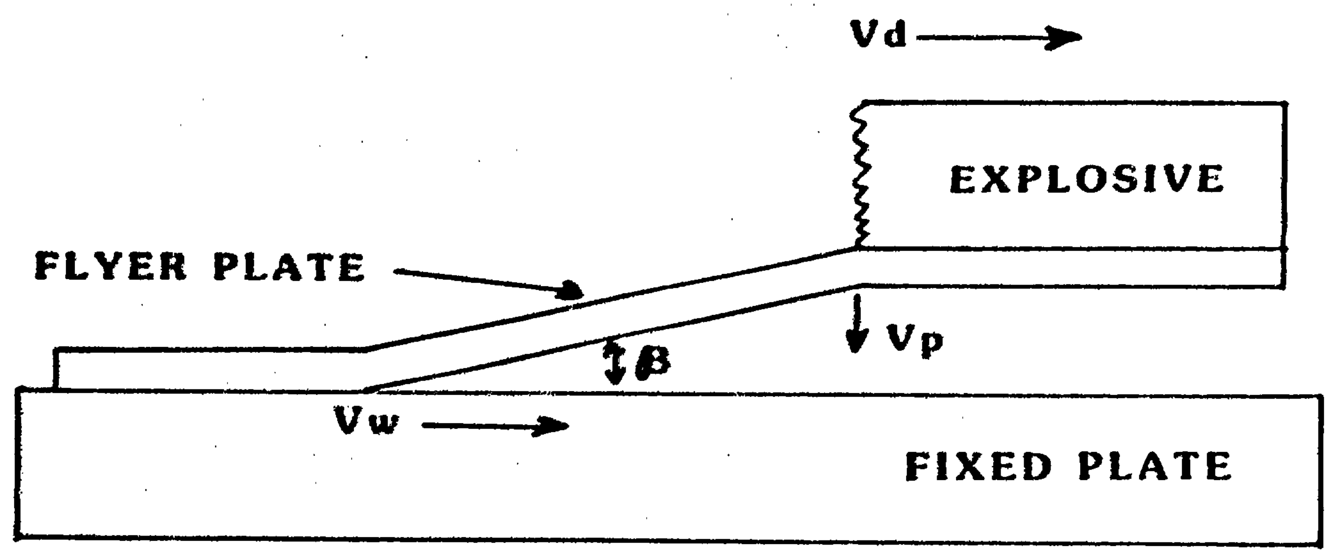

Figure 1. Schematic Diagram of Explosive Welding Progress.

$$\beta = \frac{\tan^{-1} V_p \cos \alpha/2}{V_w - V_p \sin \alpha/2} \tag{1}$$

where β is the dynamic bend angle,

V_w is the velocity of the welding point,

V_p is the flyer plate velocity, and

α is the initial angle of inclination of the flyer plate to the intended target or fixed plate.

For the current studies, $\alpha = 0$ as the flyer plate was initially mounted parallel to the fixed plate.

With α set to 0 $\quad \beta = \tan^{-1} V_p / V_w$

and $\quad V_w = V_D$

where V_D is the detonation velocity.

The Gurney equation, expression 2, gives V_p as a function of the energy and weight ratio of the explosives to the flyer plate (Sterne 1947).

$$V_p = \sqrt{2E} \sqrt{\frac{3\Phi^2}{(\Phi+1)(\Phi+4)}} \tag{2}$$

where Φ = mass of explosive/mass of flyer plate,

E is the "Gurney Energy" per unit mass of explosives,

and $\sqrt{2E}$ is the "Gurney characteristic velocity" of the explosive.

The values of $\sqrt{2E}$ and V_D have been compiled for many explosives, including DBA-10HV. Therefore, equations 1 and 2 can be used to calculate both the flyer plate velocity and the impact angle as functions of the charge to mass ratio. Although specific values of V_p and β for welding mild steel to RHA have not been reported, the values for mild steel to mild steel welding in Orava and Wittman (1975) indicate acceptable welds for plate velocities of 400 to 800 m/sec and β of 11° to 14°. The experimental parameters described in this report were adjusted so that β was approximately 11°.

2. EXPERIMENTAL PROCEDURES

The experiments were intended to demonstrate a practical method of using explosive welding to patch tanks in the field. To this end, readily available materials were used, and the design was made as simple and hazard-free as possible.

Three flyer plate designs were used in the course of the program, as shown in Figure 2. The basic design (Figure 2A) was [illegible], thin steel flyer plate, 3.2 mm x 101.6 mm x 101.6 mm, held parallel to the fixed flat plate by polymethyl methacrylate (PMMA) standoffs one plate thickness in height. The explosives were contained in a channel formed by two concentric phenolic rings, one with an outside diameter of 55.6 mm, and the second with an inside diameter of 101.6 mm. Detonation of the explosives deformed and accelerated the flyer plate, welding it in a circular pattern to the fixed RHA plate. This design was tested in two configurations; one in which the explosive was continuous around the ring, and another in which a plastic barrier interrupted the explosive. A variation on this design using a square explosive box, made from 3.2-mm PMMA and forming a 19-mm-wide track on the plate, was also tested.

The thin flyer plates could deform and tear when welded over holes in the fixed plates. To reduce the possibility of tearing, the flyer plates were modified by making them thicker in the center (see Figures 2B and 2C). Patches using the final, thick boss designs were welded first on a solid RHA plate in the laboratory and then on the glacis and turret armor of an obsolete tank.

The explosive used was DBA-10HV (Ireco Chemicals, 3000 West 8600 South, West Jordan, Utah), a slurry explosive which is mixed from a liquid component and a dry powder component, neither of which is classified as an explosive prior to mixing. DBA-10HV has a detonation velocity, V_D, of approximately 3.8 km/sec, well below the sound velocity in steel of 5.8 km/sec. The Gurney

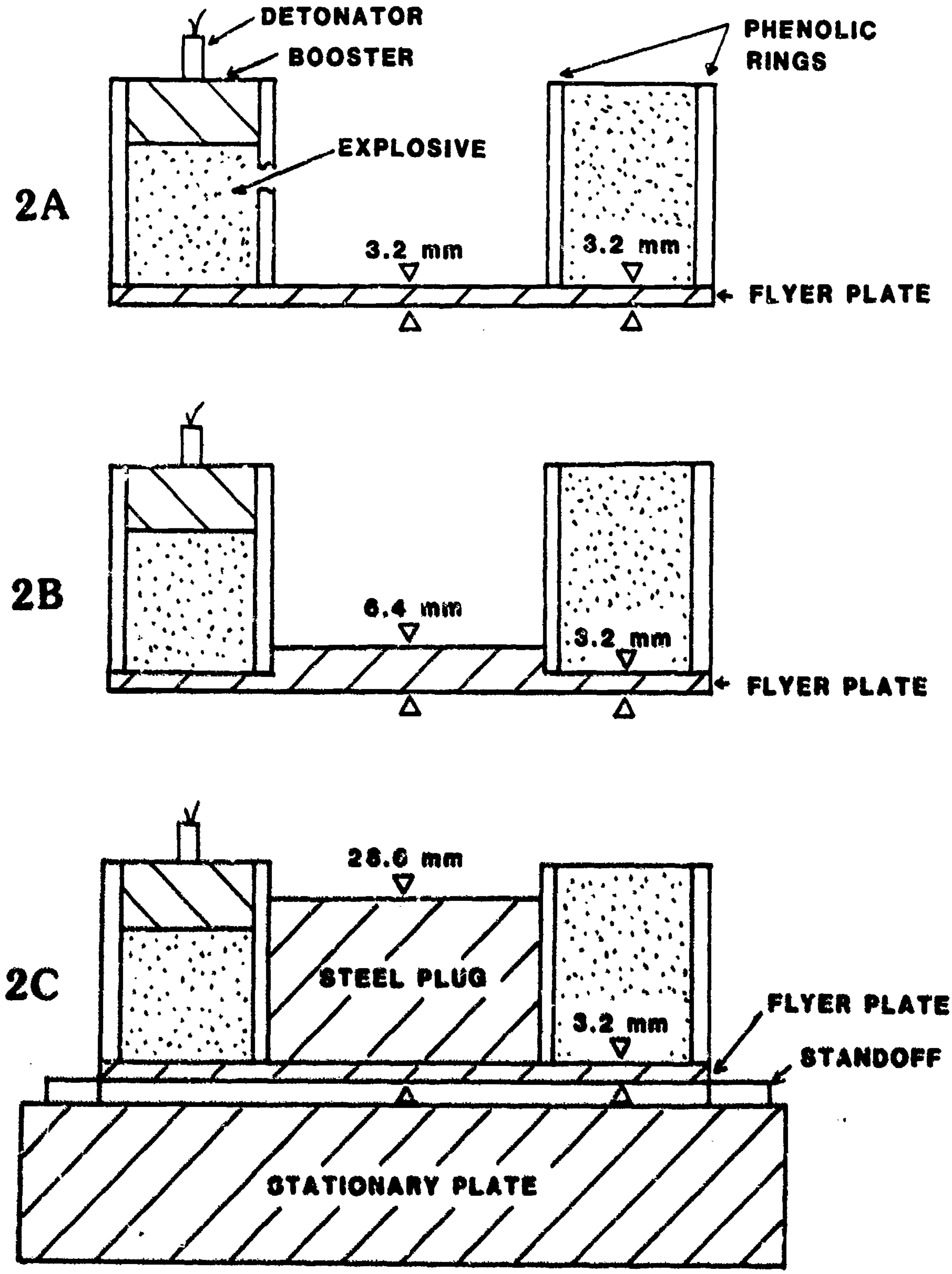

Figure 2. Basic Patch Designs. Flat Flyer Plate in 2A, Flyer Plate With Center Area Doubled in Thickness in 2B, and Flyer Plate With 25-mm-Thick Boss in 2C.

characteristic velocity, $\sqrt{2E}$, is 1.6 km/sec for DBA-10HV (Center for High-Energy Rate Fabrication 1975). The slurry gels after mixing, but never reaches a self-supporting consistency, so a water-tight container was required. A piece of Detasheet C explosive was used as a booster, placed directly in the DBA-10HV. A J-2 detonator initiated the booster explosive.

3. RESULTS

The thin flyer plates (Figure 2A) welded to the RHA fixed plates. The continuous explosive design allowed the detonation to proceed in two directions around the track and produced a poorly welded area under the initiator, with a ripple in the plate and an unbonded area at the 180° point where the two detonation fronts collided. The interrupted explosive design allowed detonation propagation in a single direction and resulted in only one poorly bonded area, under the initiator. Initially the flyer plates were square and the corners were not welded outside of the circular explosive track. The square explosive box, which loaded the corners of the plate, did weld the corners. We concluded, however, that the material in the corners of the plate did not contribute appreciably to the strength of the patch, and that a disk-shaped flyer plate with no material outside of the explosive track, which could be clipped off and thrown as a fragment, would be more efficient and safer. Disk-shaped flyer plates were used for all subsequent tests.

As is shown in Figure 3, thin flyer plates deformed and tore when welded to fixed plates containing holes, reducing their effectiveness as patches. Doubling the thickness of the center of the flyer plate (Figure 2B) strengthened the flyer plate enough to eliminate the tearing with only a dimple appearing in the boss. The tests with a 25-mm plug pre-welded to the center of the flyer plate (Figure 2C) indicated that the center of the plate could be any thickness desired.

The quality of the welds was determined by observation; no quantitative weld testing was used. Six welds were attempted in the laboratory and all were acceptable; i.e. the flyer plate appeared to be firmly attached to the fixed plate. The surfaces of the fixed plates were given different cleaning treatments (grinding, sanding, sand blasting) so that the effects of surface finish on the welds could be evaluated. The jetting action occurring in the welding process provides some self-cleaning of the surfaces, but successful bonding requires initially clean metal surfaces on both plates. No difference in weld quality was observed for the various surface preparations, however, all the fixed plates that were used were basically smooth, flat, clean, and rust free. The least perturbed welds occurred in the samples that had a gap in the explosive train.

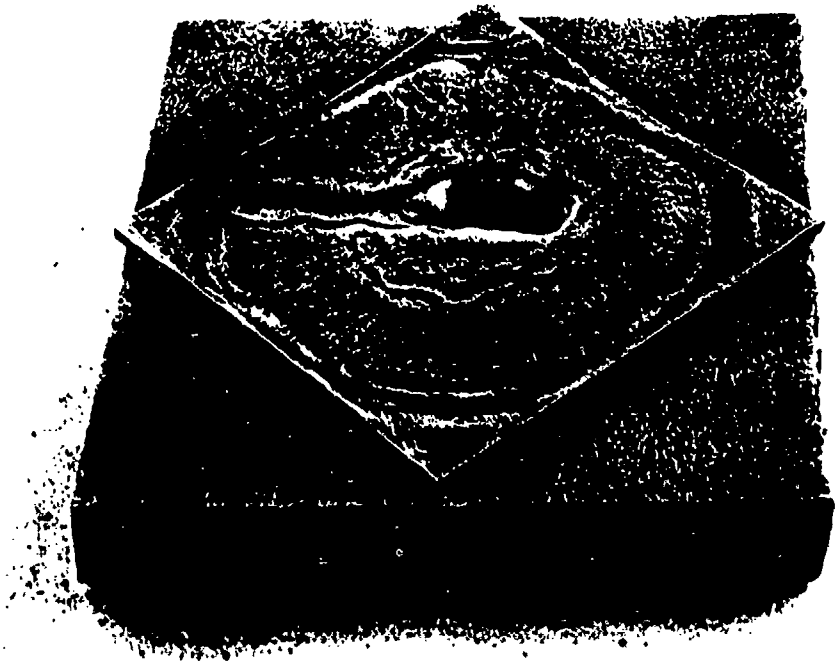

Figure 3. Weld Over Hole in RHA Plate. Portion of Flyer Plate Entered Cavity and Plate Ripped on Sharp Edge of Hole.

The patch design developed in the laboratory experiments was tested on the turret and glacis armor of a tank to show that welds could be accomplished under field conditions. The tank had been parked outdoors for many years and the originally painted armor surface was partially rusted and pitted. The initial test, where the surface was given only a cursory hand-sanding, failed to weld. However, in later tests where the majority of the welding surface was taken down to clean metal by the use of an electric sander, satisfactory welds were produced. A photograph of an explosively welded patch on the glacis armor of the tank is presented in Figure 4. As is shown in Figure 4, the flyer plate had a 25-mm-thick, 50-mm-diameter steel disk attached to its center.

4. DISCUSSION

This program was solely a feasibility study and demonstrated that an explosively welded battlefield repair patch can readily be fabricated. The design presented here was not optimized; it is very likely that adjustments to charge/mass ratio and standoff will produce better results. The flyer plate can be modified to reduce the size of the unwelded zones; a dimple in the plate under the

Figure 4. Weld on Tank With Flyer Plate Containing 25-mm-Thick Center Boss.

initiator should reduce the unbonded area there and a notch in the plate at the 180° point should let the plate weld-up to the edges of the cut and eliminate the ripple observed in these tests. The most common damage requiring a patch would be perforations in the armor from shaped charges or KE penetrators. These weapons create a bulge around the entrance hole that would make use of a flat patch difficult. A domed patch (Figure 5) would allow coverage of such damage. The center of the dome can be made thick enough to provide ballistic protection, while the thin edge can be welded to an undistorted area of the armor.

The "welded edge" design should be useful in other applications since it evades one of explosive welding's fundamental limits. If the flyer plate velocity is kept constant, the KE of the plate varies directly with plate thickness, and can exceed the limit for satisfactory welding. When only the edge is welded, the patch or fixture can have any configuration, and only the edge must meet the thickness criterion.

5. CONCLUSIONS

(1) Explosive welding can readily be used to attach steel patches or fixtures to armor plate.

(2) The metal surfaces to be welded must be clean and resonably smooth.

(3) Structures may be attached by explosively welding only the edges, minimizing the explosive required and giving greater freedom of design.

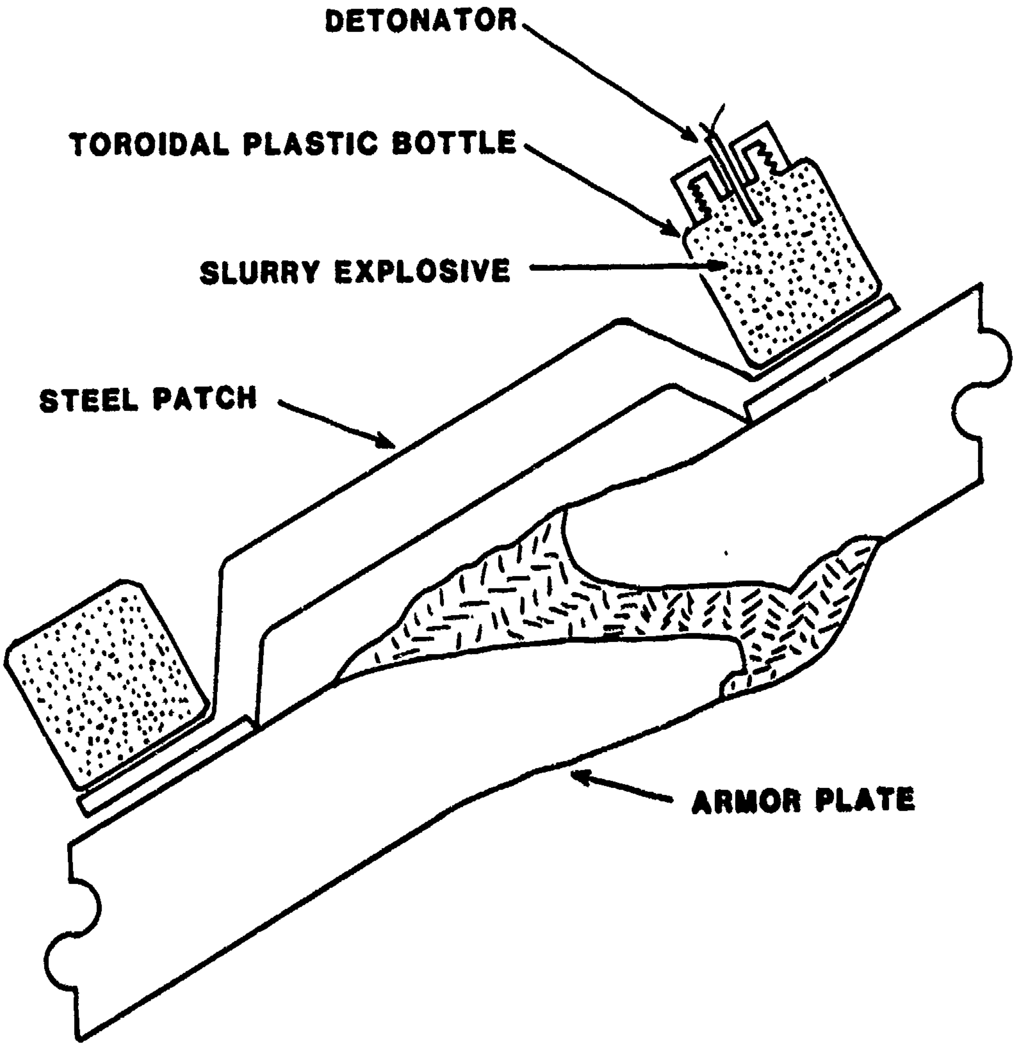

Figure 5. Conceptual Domed Explosive Patch to Cover Bulged Lip Around Projectile Impact Hole.

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